Construction and Building Materials 150 (2017) 833–843

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Understanding influence of crushers on shape characteristics of fine aggregates based on digital image and conventional techniques

Bharat Rajan *, Dharamveer Singh

Civil Engineering Department, Indian Institute of Technology Bombay, Mumbai 400076, India

HIGHLIGHTS

- The crushing mechanism showed significant effects on shape of fine aggregates.
- Aggregate produced from HSI showed the highest angularity and form 2D, followed by CC and VSI.
- The AIMS and FAA tests showed different ranking of aggregate angularity.
- The Angle of Repose test is unable to capture the effect of crushers on aggregate shape.
- The AIMS technique can be preferred over FAA for characterisation of aggregate shape.

ARTICLE INFO

Article history:
Received 8 March 2017
Received in revised form 9 June 2017
Accepted 12 June 2017

Keywords:
Angularity
Form 2D
Angle of Repose
Fine aggregate angularity

ABSTRACT

Shape characteristics of fine aggregates, namely angularity and form 2D are greatly associated with the types of rocks, mineralogical compositions, and allied crushing mechanism. Thus, for a given source and aggregate, the type of crusher may play a critical role in producing aggregates having different shape parameters. The present study was undertaken to compare shape parameters of fine aggregates produced from three different crushers, i.e. vertical shaft impactor (VSI), cone crusher (CC) and horizontal shaft impactor (HSI). Basaltic fine aggregates collected from three different crushers was divided into five sizes, namely FA1 (P4.75-R2.36: aggregate passing 4.75 mm and retaining on 2.36 mm), FA2 (P2.36-R1.18), FA3 (P1.18-R0.600), FA4 (P0.600-R0.300) and FA5 (P0.300-R0.150). The angularity and form 2D values of different sizes and types of fine aggregates were measured using Aggregate Image Measurement System (AIMS) in accordance with AASHTO TP 81. Further, conventional technique namely fine aggregate angularity (FAA) test was used to measure angularity of fine aggregates. Furthermore, Angle of Repose (AoR) test was conducted to identify influence of shape characteristics on particle packing behaviour. The study showed that both the techniques (i.e., AIMS and FAA) could differentiate among the quality of fine aggregates produced from different crushers. However, both techniques resulted in opposite trend in angularity of aggregates. The AIMS measurement showed that angularity and form 2D was highest for aggregates produced from HSI crusher followed by CC and VSI. On the other hand, FAA showed that aggregates produced from CC crusher had maximum angularity followed by VSI and HSI. Conclusively, the AIMS showed that HSI crusher could produce aggregates with highest angularity, while FAA showed that this type of crusher might produce aggregates with least angularity. Curiously, the AoR values showed no significant difference for the fine aggregates produced from different crushers. The interrelation between angularity and form 2D is also discussed in the paper.

1. Introduction

Aggregates of different sizes are used in significant proportion for production of asphalt mixes. In asphalt mixes, coarse aggregates provide major load distribution network, while fine aggregates fill the voids among coarse aggregates skeleton, and asphalt binder provides glue action for aggregates to form a monolithic asphalt mix. For dense asphalt mixes, approximately 50% of total volume is comprised of fine aggregates. Shape characteristics of fine aggregates have appreciable effects on performance of dense-asphalt mixes [1–4]. Herrin et al. [5] concluded that strength of both dense and open graded mixes increased substantially when

* Corresponding author.
E-mail addresses: bharat.rajan08@gmail.com (B. Rajan), dvsingh@civil.iitb.ac.in (D. Singh).

http://dx.doi.org/10.1016/j.conbuildmat.2017.06.058

rounded fine aggregates were replaced with crushed fine aggregates. Numerous researchers have reported similar findings on the importance of shape characteristics of fine aggregates [3,6,7]. The fine aggregate angularity (FAA) play a crucial role in providing rut resistant asphalt mixes [8,9]. Aggregate shape mainly depends on types of rocks and associated crushing mechanism [10]. Usually, different types of crushers: vertical shaft impact crusher, horizontal shaft impact crusher, cone crusher and jaw crushers are used for production of aggregates. Aggregates from different crushers may have different shape characteristics. Furthermore, sequences of crushers may also influence morphology of aggregates. The present study evaluates effects of crusher types on shape characteristics of fine aggregates. Commonly, FAA test as per AASHTO T304 [11] is used to compare angularity of fine aggregates collected from different sources. FAA is defined as amount of air void present in loosely compacted fine aggregate sample [11–13]. The basic principle behind FAA is that aggregates with more number of fracture face may provide higher air voids in a loosely compacted condition. The minimum FAA value of 45, 45–40 and less than 40 is recommended for high, moderate and low volume roads, respectively [14]. Though FAA test is considered to be a good tool to evaluate quality of fine aggregates [8,15], some researchers have reported that FAA is unable to discern between high-quality and poor-quality of fine aggregates due to its indirect nature of measurement [13,16–18]. The value of FAA may change with number of factors, such as aggregates specific gravity, drop height, precision in weight measurement, etc. Thus, a better test method is required to measure reliable angularity properties of fine aggregates. Recently, digital image techniques are applied to overcome difficulties involved in the measurement of fine aggregate angularity using conventional test method [19]. The digital image technique defines shape of aggregate in a hierarchical order using three independent factors, namely form, angularity and texture [20]. The form is a first order property and shows variation in proportion of an aggregate. Angularity is defined as a second order property and shows sharpness at corners. The third order property, surface texture is defined as small-scale irregularity of surface. Moreover, scale of measurement for surface texture is too small to affect overall shape. Masad et al. [21] measured shape indices (i.e. angularity, form 2D, and texture) of twenty-two different fine aggregates samples using Aggregate Image Measurement System (AIMS). They concluded that form 2D of fine aggregates was not affected by angularity, while texture showed a strong correlation with angularity. Therefore, shape of fine aggregates is classified on the basis of only two different shape characteristics: angularity and form 2D [1,26]. Recently, a set of new standards, namely AASHTO TP81-12 [22] and AASHTO PP64-11 [23] has been prepared by AASHTO to, measure aggregate shape, characterise aggregate source and determine cumulative shape indexes for given aggregate gradation by means of digital image technique.

So far to the author's understanding, no studies have been conducted to compare shape parameters of fine aggregates produced from different types of crushers. Further, comparison between angularity measured using conventional test method (FAA) and digital techniques have not been reported. In the present study, fine aggregates of five different sizes: FA1 (passing a sieve of 4.75 mm and retained a sieve of 2.36 mm (P4.75-R2.36), FA2 (P2.36-R1.18), FA3 (P1.18-R0.600), FA4 (P0.600-R0.300) and FA5 (P0.300-R0.150) were collected from three types of crushers: vertical shaft impactor (VSI), cone crusher (CC) and horizontal shaft impactor (HSI). The angularity and form 2D of all types of fine aggregates were measured using AIMS in accordance to AASHTO TP81-12 [22]. Further, FAA of fine aggregates was measured using AASHTO T304 [11]. In addition, Angle of Repose (AoR) of fine aggregates was measured and compared with their shape characteristics. It is anticipated that outcomes of the present study would provide better insight into quality of fine aggregates produced from different crushers.

2. Objectives

The objectives of the present study are to:

- Compare angularity and form 2D of fine aggregates produced from three different crushing operations (i.e., VSI, CC and HSI), measured using AIMS.
- Correlate packing and stability behaviour of fine aggregates measured using conventional laboratory tests (i.e., FAA and AoR) with angularity and form 2D of fine aggregates obtained from AIMS.

3. Materials and crushers

In the current study, basaltic fine aggregates produced from three different types of crushers, namely vertical shaft impactor (VSI), cone crusher (CC) and horizontal shaft impactor (HSI) were collected. The VSI works on aggregate to aggregate impact mechanism. The aggregate was allowed to fall through spacing on centre and circumference. Centre fall aggregates were provided high centrifuge velocity against a cascade of circumferential aggregates. The crushing in the CC is a combination of abrasion and cleavage phenomena, which is generated due to trapping of aggregates between rotating cylinder and fixed hard wall surface. The HSI works on aggregate to anvil impact mechanism. The impact is generated by the collision of aggregates with high-speed blades and fixed anvils (Table 1). The fine aggregates were divided into five different sizes, namely FA1 (passing a sieve of 4.75 mm and retained a sieve of 2.36 mm (P4.75-R2.36), FA2 (P2.36-R1.18), FA3 (P1.18-R0.600), FA4 (P0.600-R0.300) and FA5 (P0.300-R0.150).

4. Experimental plan

First angularity and form 2D of different types and sizes of fine aggregates were measured using AIMS. Thereafter, FAA and Angle of Repose (AoR) of fine aggregates were measured to understand particle packing behaviour. Table 2 shows the test matrix. Total 15 different types (5 sizes $\times$ 3 crushers) of aggregates samples were tested in the study (Table 2). A systematic statistical analysis approach was used to compare shape parameters of aggregates produced from different crushers. First, the outliers from datasets were removed using whisker-box plot method. The normality of data set was tested using D'Agostino-K-squared test [24]. Thereafter, the variance was compared with the help of Levene's F-test at a significance level of 0.05. Finally, mean values were compared using Analysis of variance (ANOVA) test at significance level of 0.05. The study uses Origin [25] for normality test, while F-test and ANOVA test analyses were done with help of SPSS® [26].

4.1. Measurement of shapes using AIMS

Different size of aggregates (FA1, FA2, FA3, FA4, and FA5) were washed and oven dried at 110 °C before testing in AIMS. A representative sample of 500 gm of each size was selected through standard sample split mechanism as per ASTM D75 [27]. The angularity and form 2D of total 300 fine aggregates particles from each size fraction were measured in two consecutive trials (150 particles in each trial) using AIMS (Fig. 1a). The AIMS is an automated device consists of a high-resolution camera with a variable magnification microscope, aggregate tray, backlighting and top-lighting systems [28; Fig. 1a], capable of measuring angularity and form 2D of fine aggregates size ranging from 4.75 mm to 0.075 mm.